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DISASSEMBLABILITY AND REASSEMBLABILITY PARAMETERS ANALYSIS: AUTOMOBILE MAINTENANCE CONTEXT STUDY

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ABSTRACT

The purpose of this paper is to study the disassembly and reassembly criteria and parameters in the maintenance activities context although such initiative has been tabled for other purposes like recycling, remanufacturing, etc. Measuring Dis/re-assembly activities is a complex task due to the various variant disassembly metrics and contexts. Time spent for dis /re-assembly faulty component should be well-deducted and standardized based on appropriate selected disassembly parameters. So, we present a methodology for modeling and selecting the appropriate maintenance dis/re-assembly metrics. The frequent observation in the literature relate work and a survey analysis during dis/re-assembly activities have been fit together in order to deduct the adequate dis/re-assembly metrics.Based on relate topic literature analysis and our own experimentation carry out in different organizations, through statistical methodology outlines here, a relevant dis/re-assembly metric model has been cleared.According to the well-characterized context, this model will contribute as root of evaluating the maintenance task such as disassembly and reassembly for better maintenance services. The paper rounds off with conclusions and an agenda for future research in this area.

KEYWORDS: Disassemblability, Reassemblability, Evaluation, Disassembly/Reassembly Metrics, Modeling, Maintenance

INTRODUCTION

In the engineering context, disassembly may be defined as the organized process of taking apart a systematically assembled product (assembly of components). Products may be disassembled to enable maintenance, enhance serviceability and/or to achieve End-Of-Life (EOL) objectives such as product reuse, remanufacturing, and recycling.

Nowadays, a company that wishes to stay in the market for a long time must innovate. The environmental issue become very consciousness and designer is struggling for more product sustainability and total re-engineering. Disassembly can then play an important role in reverse engineering issue. Daniel et al. (2006) mentioned that disassembly is a strategy that helps reducing environmental impact in the use phase, since, if a product is easy to disassemble, it will be possible to repair it more easily and therefore its service life will be increased. Besides, it is a necessary and critical process in the end-of life option. Therefore, Design for Disassembly (DFD) has become a key design issue to achieve optimal EOL treatments in mass-produced consumer products (Sheety et al, 2000), and there has been much research on how to design products for easier disassembly. Much of this research emphasizes disassembly to make recycling easier (Henstock et al. 1988; Chen et al. 1993; Kirbly et al. 1993; Noller et al. 1992), whilst other studies extend to include disassembly for remanufacture (reuse) (Simon et al. 1991; Zussman et al. 1994; Amezquita et al. 1995). Designer need today adequate methodology measuring disassembly so that one can improve disassemblability degree while maintenance manager wants

the precedent tool for more productivity, less and less down times. Maintenance measurement is based on time spend to perform some maintenance operations. The problem in measuring the time required for maintenance operations such as disassembly is that the work is highly variable. Even the same job can have different times on different occasions. For this reason is not ease to determine with conventional accuracy the time for individual jobs. Since maintenance work is not highly repetitive and any one maintenance worker will usually complete several jobs each month.

Disassembly is still manual in nature and timing such activity is not only narrowly link to movement of object as related Zandin (1990), but also to the quality of manual output and security of the worker while performing the task. It has been observed that reassembly takes also considerable time intervention due sometimes to equipment re-functioning requirements. For example in the case of maintenance activities, maintenance actor has his own experience level and should spend adequate time to perform a task while thinking of optimal equipment re-functioning. So, there is no really speed in maintenance intervention context.

Timing a job is not an easy task as we earlier mentioned, especially when recording standard time is needful precisely in the competitive maintenance area. It for this reason that we prefer starting in this paper by finding out appropriate disassembly/reassembly metrics among a full range of them. So we should start by gathering previous literature disassembly/reassembly metric. Set a questionnaire in order to select the appropriate disassembly/reassembly parameters based on maintenance condition and environment. This should be a prerequisite for looking ahead maintenance time measurement and optimization and will be helpful to fulfil such maintenance efficiency and requirement, although maintenance disassembly/reassembly time is not yet standard.

LITERATURE RELATED WORK

Various methodologies have been developed to evaluate the disassemblability of a product. The methodologies vary from the methodologies that use the spread sheet-like chart, energy use, entropy for disassembly, time, to the end-of-life value of a product. Such disassembly evaluation based their analysis on disassembly parameters that condition design for disassembly. Those parameters are very variant according to each author initiative.

While applying TRIZ for gathering DFD parameters in other to innovate in DFD, Daniel et al. (2006) remind that the parameters that affect the disassembling process are determined by the activities made before, during and after (Mok et al. 1997); on the other hand, there is also a series of factors that affect the product’s design, when it is conceived taking into account its disassembly. All these factors have been transformed into six groups, selected from references (Mok et al. 1997; Behrendt et al. 1997; Singh, 1996):

- Product structure
- Types and number of joints
- Characteristics of the parts to disassembly
- Final use of the parts
- Visibility of the joining elements
- Disassembly conditions

All these factors can be improved using the strategies or guides shown in table 1.

Table 1: Factors and Strategies or Guides to Improve Disassembly (Daniel et al, 2006)

Factors that Affect the Disassembling Process	Guides or Strategies to Improve the Disassembly
Product structure	Create a hierarchical structure Use a modular design Make use of components standardizations Minimize product variety Minimize number of components Minimize number of different materials Use materials that can be recycled
Types and number of joints	Use joints that are easy to disassemble Assure access to connecting elements Minimize number of joints
Characteristics of the parts to disassembly	Good accessibility, low volume, low weight, low fragility, no danger, etc.
Final use of the parts	To allow its maintenance, to increase its service, etc. At its EOL, reuse, remanufacture, recycle or to incinerate
Visibility of the joining elements	Mark non obvious joints Avoid non visible joints
Disassembly conditions	Create good conditions for mechanical automatic disassembly Use of usual all-purpose tools

In the light of implementing Altshuller ideas in the gathering of disassembly parameters, 39 engineering parameters have been analyzed (Altshuller, 1986) in order to find which of them may have an effect on the type of joint. After this analysis, the initial number of parameters has been reduced to the 30 parameters included in table 2 and the possible contradictions among the 30 parameters have been identified. To accomplish this, the fact that the improvement of one parameter can worsen another one has been taken into account. The contradictions matrix selects the inventive principles in order to break the contradiction.

Table 2: Engineering Parameters Which May Affect the Type of Joint (Daniel et al, 2006)

1- Weight of moving object 3- Length of moving object 5- Area of moving object 7- Volume of moving object 9- Speed 10- Force 11- Tension/ pressure 12- Shape 13- Stability of object 14- Strength 15- Durability of moving object 17- Temperature 19- Energy spent moving object 21- Power 23- Energy loss	24- Loss of information 25- Waste of time 26- Amount of substance 27- Reliability 29- Accuracy of manufacture 30- Harmful factors acting on object 31- Harmful side effects 32- Manufacturability 33- Convenience of use 34- Repairability 35- Adaptability 36- Complexity of device 37- Complexity of control 38- Level of automation 39- Productivity

Based on the Mok et al, (1997) disassemblability is defined as the degree of easiness of disassembly; inversely reassemblability is the degree of easiness reassembly. Mok also analyses disassembly mechanism between parts and sub-assemblies to improve disassembly process in a scrapped automobile. Concepts for disassemblability include:

- Disassembly without force
- Disassembly by simple mechanism
- Disassembly without tools
- No repetition of using the same part or similar parts
- Easy recognition of disassembly points
- Design of simple structured
- No use of toxic materials in products

When these concepts are realized in disassembly process, technical and structural problems occur. These problems can be solved by redesign of products, development of new joining methods and standardization of parts and subassemblies.

Disassembly mechanism can be divided into disassembly with force and disassembly without force, when the product is disassembled. Disassembly directions are also important for the study of disassembly mechanism. There are some factors that can be determined for disassemblability based on disassembly mechanism: clamping of force (ease of fixing); approaching of tools to product (ease of finding joining point, ease of approaching and ease of handling); transfer of force (ease of disjoining); separation between parts (ease of handling); sorting of part (ease of retrieving); reuse (ease of cleaning, ease of dissolving). Also magnitude of disassembly system parameters based on disassemblability is quoted: Handling mechanism, joining mechanism, joining force, disassembly direction, working space, inspection mechanism, alignment mechanism, transport mechanism, disassembly sequence and degree of automation. Table 3 below sketches part and process parameters.

Table 3: Magnitude of the Disassembly System Parameters According To Ease of fixing (Mok **et al. 1997)**

Disassembly System Parameter			
Part Parameter		**Process Parameter**	
Structural Aspect	**Organizational Aspect**	**Pre-Process**	**In-Process**
Contact condition Symmetry Fling up Interlocking Joint point Center of gravity Grip point visually Joining element Roughness Weight Tolerance Size Material Strength Shape	Product structure Variant Standardization Number of part	Inspection mechanism Alignment mechanism Transport mechanism Disassembly sequence Degree of automation	Handling mechanism Joining mechanism Joining force Disassembly direction Working space

Kroll and Carver (1999)examine the problem of assessing product ease of disassembly for recycling. The disassembly time estimation method outlined is shown to provide one of several metrics for use during product design. Numerous disassembly experiments conducted over several years indicated that four different sources of difficulty in performing dismantling tasks should be conducted in order to provide design feedback: accessibility, positioning, force and

base time. A fifth source (special) was added to account for various non-standard effects. They present a method for estimating disassembly time, which is suitable for incorporation into the analysis phase of concurrent design. The chosen means for computing the time spent doing various actions was the MOST work-measurement system.

AnilMital and Anoop (2003) Desai stated that the use of force, mechanism of disassembly, use of tools, repetition of parts, recognizability of disassembly points, product structure, and use of toxic materials affect the disassemblability. They reveal also the lack of consider crucial factors such as:

- The magnitude of manual force required to effect disassembly;
- The need for specialize manual tools in order to facilitate disassembly;
- Accessibility issues to enhance quick and easy disassembly;
- The need for the assumption of irregular working postures for a prolonged period of time.

The disassemblability evaluation is based on weightage to numerous factors such as size and shape of components being disassembled, weight, frequency of disassembly tasks, requirement of manpower, postural requirements and material handling requirements. A number of a human factors in addition to design and economic factors merit consideration due to high labor intensiveness of the disassembly process.

McGlothin and Kroll (1995) designed the spread sheet-like chart to measure the ease of disassembly of a product. The authors categorized the disassembly difficulties into 5 subjective categories, accessibility: a measure of the ease with which a part can be accessed, positioning: a measure of how precisely the tool or hand needs to be positioned and oriented in order to perform the task, force: a measure of the amount of force required performing the task, additional time: while each of the previous difficulty sources is related to time, this category has to do with additional time penalties, special: this is a provision to note special problems encountered that do not fit in any of the other categories.

There are some additional time which must be taken into consideration call masque time or micro-time (Preparation time, movement time). That is the justification of the presence of the coefficient in the formula. Those times could be linked to some actions: preparing tools, change tools, component constantly being check, time taken to respect all design and manufacturing prescription, moving around, blown component, etc.

METHODS

A wide range of disassembly parameters has been analyzed in the precedent relevant literature based on subjective approach either for design for total recycling through disassembly time and cost measurement or for design for maintenance amelioration purpose. We are now struggling to initiate a statistical approach selecting relevant disassembly/reassembly parameters in order to ease the effective and technical task time of maintenance disassembly and reassembly operations. Looking for maintenance disassembly task time should be based on appropriate definition of disassembly criteria and their parameters.

A survey has been carried out in the automobile concessionaire here in Cameroon such as: SOCADA, CAMI Toyotaand TRACTAFRIC. Automobile Disassembly/reassembly actors have been interviewed based on different practical and contextual questions. A part of questionary sketch is depicted on the following tables (4 and 5) below.

Table 4: Part of Questionnaire Sketch for Disassembly/Reassembly Parameters

Disassembly /Reassembly Parameters	Answers		
Time spent to disassemble product depend on :			
Fastener characteristic: weight, diameter, thread, etc.	Yes ☐	No ☐	Sometimes ☐
Accessibility to the fastener	Yes ☐	No ☐	Sometimes ☐
Visibility of the fasteners	Yes ☐	No ☐	Sometimes ☐
Force of the Maintenance Actor	Yes ☐	No ☐	Sometimes ☐
Posture of the Maintenance Actor	Yes ☐	No ☐	Sometimes ☐
Experience (recurrence of performing same task)	Yes ☐	No ☐	Sometimes ☐
Repetition of disassembly the same fastener	Yes ☐	No ☐	Sometimes ☐
Work environment (logistic, climate, etc.)	Yes ☐	No ☐	Sometimes ☐
Degree of wear, seizing and break of fastener	Yes ☐	No ☐	Sometimes ☐
Tool used (standard tool, robot)	Yes ☐	No ☐	Sometimes ☐
Working method of each Maintenance Actor	Yes ☐	No ☐	Sometimes ☐
Endurance (quantity of work load over a period)	Yes ☐	No ☐	Sometimes ☐
Product state (new, old)	Yes ☐	No ☐	Sometimes ☐

Table 5: Part of Questionnaire Sketch for Task Management

Disassembly/Reassembly Task Management	Answers		
Is it frequent that the one who disassembles is not the one who reassembles?	Yes ☐	No ☐	Sometimes ☐
Do you perform disassembly with assistance of someone?	Yes ☐	No ☐	Sometimes ☐
Do you often break fasteners during disassembly?	Yes ☐	No ☐	Sometimes ☐
Do you always motivate to disassemble?	Yes ☐	No ☐	Sometimes ☐
Why are you motivated (Salary, Work love, Extra hour)?	Yes ☐	No ☐	Sometimes ☐
Do you use to work under pressure of time?	Yes ☐	No ☐	Sometimes ☐
Is there sometimes any lack of material?	Yes ☐	No ☐	Sometimes ☐
Is there a work standard method for each task?	Yes ☐	No ☐	Sometimes ☐
Do you use to time your work?	Yes ☐	No ☐	Sometimes ☐
Do you respect the rest time?	Yes ☐	No ☐	Sometimes ☐
Do you always do the extra hour?	Yes ☐	No ☐	Sometimes ☐
Are you specialist for a particular intervention?	Yes ☐	No ☐	Sometimes ☐

RESULTS

Given a control period of time, one can analyze in the context of automobile maintenance what disassembly and reassembly time depend on. A questionnaire has been submitted to 130 disassembly and reassembly technicians and a recap of answer has been recorded as presented in the tables (6 and 7) below either for gathering disassembly/reassembly parameters or for defining disassembly/reassembly management and well-framework experimental context. The answer Yes, No or Sometimes is expressed in percentage.

Table 6: A Recap of Answer about Disassembly Parameters

Disassembly /Reassembly Parameters	Codification	Yes (%)	No (%)	Sometimes (%)
Fastener characteristic: weight, diameter, thread, etc.	P1	84,62	0	15,38
Accessibility to the fastener	P2	100	0	0
Visibility of the fasteners	P3	84,62	15,38	0
Force of the Maintenance Actor	P4	84,62	15,38	0
Posture of the Maintenance Actor	P5	84,62	15,38	0
Experience (recurrence of performing same task)	P6	84,62	15,38	0
Repetition of disassembly the same fastener	P7	69,23	30,77	0
Work environment (logistic, climate, etc.)	P8	92,31	7,69	0
Degree of wear, seizing and break of fastener	P9	84,62	15,38	0
Tool used (standard tool, robot tool, special tool, etc.)	P10	61,54	7,69	30,77
Working method of each Maintenance Actor	P11	53,85	0	46,15
Endurance (quantity of work load over a period	P12	100	0	0
Product state (new, old)	P13	76,92	0	23,08

By using correspondences factors analysis with the help of XLSTAT (Data analysis software), the figure below presents the reciprocal relations between parameters and classifies them according to the answers Yes, No and Sometimes. It has been gathered in three groups. The first one is constituted (P1, P2, P3, P4, P5, P6, P8, P9, P10, P12, P13) based on YES answer, the second one is formed (P11) based on Sometimes answer and the last one is composed with (P7) based on No answer. It now ease to justify which parameters should be chose for further experimental study.

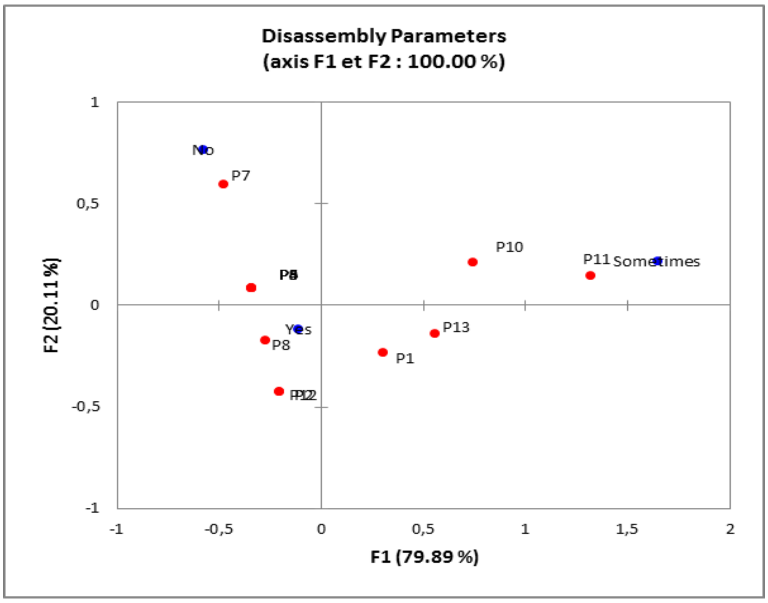

Figure 1: Parameters Correlation on Factorial Axis F1XF2

Table 7: A Recap of Answer about Disassembly Work Management

Disassembly /Reassembly Management	Codification	Yes (%)	No (%)	Sometimes (%)
Is it frequent that the one who disassembles is not the one who reassembles?	M1	**38,46**	**61,54**	**0**
Do you perform disassembly with assistance of someone?	M2	**7,69**	**15,38**	**76,92**
Do you often break fasteners during disassembly?	M3	**53,85**	**7,69**	**38,46**
Do you always motivate to disassemble?	M4	**69,23**	**0**	**30,77**
Why are you motivated (Salary, Work love, Extra hour)?	M5	**23,08S**	**0**	**76,92a**
Do you use to work under pressure of time?	M6	**23,08**	**23,08**	**53,85**
Is there sometimes any lack of material?	M7	**61,54**	**0**	**38,46**
Is there a work standard method for each task?	M8	**76,92**	**23,08**	**0**
Do you use to time your work?	M9	**61,54**	**23,08**	**15,38**
Do you respect the rest time?	M10	**30,77**	**15,38**	**53,85**
Do you always do the extra hour?	M11	**0**	**38,46**	**61,54**
Are you specialist for a particular intervention?	M12	**46,15**	**53,85**	**0**

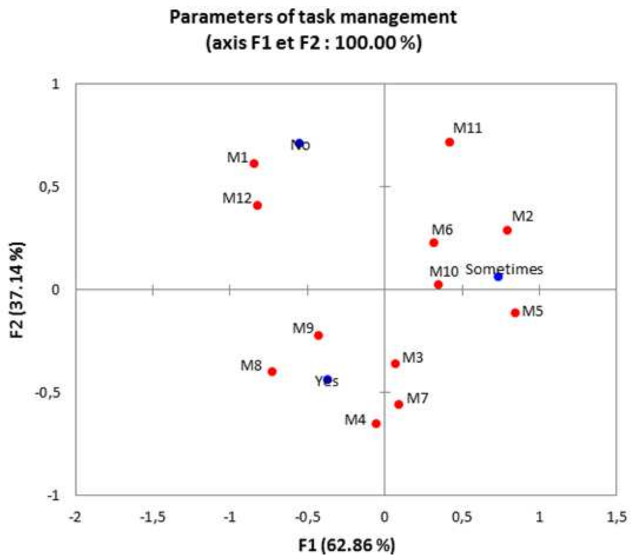

Figure 2: Parameters of Disassembly Management Correlation on Factorial Axis F1XF2

With the same precedent method analysis, the figure 2 illustrates three groups of disassembly/reassembly management according to Yes (M3, M4, M7, M8, M9), No (M1, M12) and Sometimes answer (M2, M5, M6, M10, M11). The lesson here is that, in view to carry out experimental study in order to find out how disassembly time behaves, an adequate framework should be well-defined based on this disassembly management result. Carrying out such activities need a clarification of the according context.

Literature has evaluated disassembly time based on limited parameters. A deep disassembly analysis encompasses many criteria and parameters that should be considered and need to evaluate their weight in the disassembly time process in order to define the relevant one. Precisely in the automobile disassembly context, various variant parameters have been quoted and classified after analyzing by the dis/re-assembly technicians.

CONCLUSIONS

The objective here was to define and to select the dis/re-assembly criteria and their parameters that can help as root condition to measure dis/re-assembly time in the automobile maintenance context. Disassembly and reassembly are one of the critical operations in the automobile maintenance context. So maintenance optimization is literally maintenance time optimization. Dis/re-assembly parameters have been selected and classified. This will help for studying their impact in the disassembly time In order to provide manager a method for assessing maintenance performance through dis/re-assembly operation measurement by knowing effective dis/re-assembly time.

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